A Review of Estimate at Completion Research

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A REVIEW OF ESTIMATE AT COMPLETION RESEARCH[1]

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ABSTRACT

The cancellation of the Navy's A-12 program has increased interest in forecasting the completed cost of a defense contract, termed "Estimate at Completion" (EAC). In addition, popular software packages and electronic spreadsheets allow users to quickly compute a range of EACs. Analysts and managers are left with the task of deciding which EAC or range of EACs is most accurate. Although there have been many studies that either compare existing EAC formulas and models, or propose new ones, few have been published in journals or magazines and there is little guidance regarding which formula or model is most accurate. This paper reviews 25 studies which either propose or compare EAC formulas and models. Each study is briefly described. Tables which summarize research results are provided. Results show that no one formula or model is always best. Additional research with regression-based models is needed.

INTRODUCTION

On 7 January, 1991, Defense Secretary Cheney announced that the Navy's A-12 program was cancelled.[2] Although there were many reasons for the A-12 cancellation (Beach, 1990), certainly the problem of estimating its completed cost was an important contributing factor. Regarding this estimate, Secretary Cheney complained that "no one can tell me exactly how much it will cost to keep [it] going" (Morrison, 1991:30).

In fact, there were many estimates of its cost. Beach reported that the Navy's program manager chose to rely on a lower estimate, despite several higher ones presented by his own analyst. Beach also suggested that "abiding cultural problems" effectively suppressed the more pessimistic estimates. Navy Secretary Garret voiced a similar conclusion. In testimony before the House Armed Services Committee, Secretary Garret dismissed serious errors in judgment by senior career people involved with the A-12 by saying that they were "can-do" people who would not admit failure lightly (Ireland, 1991:27).

Of course, such cultural problems are not unique to the Navy. Using the same data, Department of Defense, Service, and contractor analysts often disagree about estimated completion costs. Although some of the disagreement may be attributed to cultural bias, the problem of accurately estimating the completed cost of a defense contract remains.

In the last sixteen years, there have been a large number of studies which have explored the problem of estimating the completed cost of defense contracts. Only a few of these "Estimate at Completion" studies have been published in journals or magazines generally available to interested readers. Most are theses, cost research reports, or special studies and remain "buried" in cost and technical libraries. This paper reviews 25 of these studies, collectively named "Estimate at Completion Research." Its purpose is to inform the reader of the results of this research, generate insight into the appropriate use of Estimate at Completion (EAC) formulas, and identify areas for additional research.

The paper is divided into three parts. In the first part, EAC formulas are briefly described and categorized. In the second part, non-comparative studies which advocate or introduce new EAC methodologies, are briefly reviewed and summarized in a table. In the last part, comparative studies, which compare the actual cost of completed contracts against various EAC formulas, are reviewed and summarized in a table. Generalizations based on this review conclude this paper.

[1] *Journal of Cost Analysis and Management*, Spring 1995, pp.41-62.

[2] Technically, the A-12 full-scale development contract was "terminated for default."

EAC FORMULAS

The EAC can be computed by formula using cost management data provided by the contractor to the Government in the *Cost Performance Report* or the *Cost/Schedule Status Report*. The studies reviewed in this paper assume that data presented in these reports are reliable. The reliability of the data depends upon the degree to which the contractor adheres to a strong system of internal controls involving the scheduling, budgeting, and analysis of contractual effort. See Department of Defense Instruction 5000.2, *Defense Acquisition Management Policies and Procedures,* for a description of these controls.

All EAC formulas are based on the combination of several data elements presented on the cost management report: Budgeted Cost of Work Scheduled (BCWS); Budgeted Cost of Work Performed (BCWP); and Actual Cost of Work Performed (ACWP). These data elements are usually reported monthly. Cumulative and averaged data can then be computed through the period of the contract's life.

For this paper, EAC formulas are classified into three categories: index, regression, and other. The generic index-based formula is shown in Equation 1:

$$\text{EAC} = \text{ACWPc} + (\text{BAC} - \text{BCWPc})/\text{Index} \qquad (1)$$

The subscript "c" indicates cumulative data. Budget at Completion (BAC) is the total budget for the identified work. Detailed descriptions of these and other related terminology are presented elsewhere (e.g., Air Force Systems Command Pamphlet 173-4, Guide *to Analysis of Contractor Cost Data)*.

The index, normally some combination of ACWP, BCWP, and BCWS, is used to adjust the budgeted cost of the remaining work on the contract (BAC –BCWPc). The assumption implicit in this adjustment is that the contract's past cost and schedule performance is recurrent and reflective of future performance. For this paper, these "performance indices" are classified into four groups:

$$\text{Cost Performance Index (CPI)} = \text{BCWP}/\text{ACWP} \qquad (2)$$
$$\text{Schedule Performance Index (SPI)} = \text{BCWP}/\text{BCWS} \qquad (3)$$
$$\text{Schedule Cost Index (SCI)} = \text{SPI X CPI} \qquad (4)$$
$$\text{Composite Index} = \text{W1 X SPI} + \text{W2 X CPI} \qquad (5)$$

The weights shown in Equation 5 (W1 and W2) can take on any value from 0 to 1, and normally add to unity.

These indices can be based on monthly, cumulative, or averaged data. For this paper the following labeling conventions are adopted: "CPIm" represents a CPI based on the most recent month; "CPIc" represents cumulative CPI; "CPIx" represents a CPI averaged over x number of months, beginning with the most recent month and going backwards. For example, CPI3 represents a 3 month average CPI, with the current and the last two previous months included. SPI and SCI use the same conventions. For example, "SCI6" is a six month average SPI, with the current and the last five months included.

The indices can be averaged in two ways. Usually, the averaged index is defined as a ratio of sums through x months:

$$\text{CPIx} = \sum \text{BCWPx} / \text{ACWPx} \qquad (6)$$
$$\text{SPIx} = \sum \text{BCWPx} / \text{BCWSx} \qquad (7)$$

An alternative definition is to divide sum of the monthly indices by the appropriate number of months:

$$\text{CPIx} = (\sum \text{CPIm}) / x \qquad (8)$$
$$\text{SPIx} = (\sum \text{SPIm}) / x \qquad (9)$$

Unless specified otherwise, this paper defines an averaged index according to Equations 6 and 7.

The second and third categories of EAC formulas are termed "regression" and "other." The regression-based formulas are derived using linear or nonlinear regression analysis. For this paper, nonlinear regression analysis is defined as the analysis of a nonlinear relationship, regardless of whether it van be transformed into a linear relationship[3]. In any case, the dependent variable is usually ACWP, and the independent variable(s) is usually BCWP, a performance index, or time. The "other" category is for any formula that is not in the first two categories, such as formulas based on heuristics.

It is apparent that there are in infinite number of possible EAC formulas. The analyst is left with the interesting task of deciding which formula or group of formulas to use. Performance Analyzer (Scifers, 1991), a popular analysis software package, allows the user to chose from a variety of formulas. However, no guidance is provided regarding which formula or group of formulas is most accurate. The remaining parts of this paper will address this issue by reviewing EAC research conducted over the past sixteen years.

NON-COMPARATIVE STUDIES

Non-comparative studies do not compare EAC formulas and models. Instead, they describe a "new" formula or forecasting methodology. Generally, each of these studies involves a complicated heuristic or statistical technique that does not lend itself well to comparative analysis. Table I summarizes 13 non-comparative studies by author, year, Service (or sponsoring organization), and forecasting methodology. ("DLA" is Defense Logistics Agency. "DSMC" is Defense Systems Management College.)

Several of the studies listed have more than one author. To save space in the table, only the name of the first author is listed. See "References" for a complete listing of authors. A brief description of each study follows:

Index-based methods. Four of the noncomparative studies proposed ways to develop weights for the composite index. Jakowski (c1977) and Lollar (1980) suggested formulas for deriving weights. Parker (1980) and Totaro (1987) suggested that the weights be subjectively assigned. Because the SPI is driven to unity at contract completion by definition, these studies generally suggest that the SPI eventually looses its information content. Accordingly, the weight assigned to the SPI should decrease to zero as the contract progresses to completion. In a fifth study, Haydon (1982) derived a point estimate from a range of EACs computed by several index-based formulas.

Jakowski (Navy Aviation Systems Command, c1977) proposed a rather complicated heuristic for determining the weights of the composite index. First, CPIc is used until there are significant decreases in the most recent monthly CPIs. When this happens, an "optimally weighted" composite index is used. The optimal weighting is defined as that weight which results in the least historical standard deviation in the composite index. After 60% completion point, CPIc is again used. Original documentation for Jakowski's heuristic could not be located, but is described by Covach, et al. (1981:24).

Lollar (Aeronautical Systems Division, 1980) proposed defining the weights for cumulative SPI and CPI as the relative contribution which the absolute values of schedule and cost variance percentages make to their total. Blythe (1982) and Cryer (1986) included Lollar's method in their comparative studies. It did not do well against the other formulas.

Parker's (Defense Logistics Agency, 1980) method consists of simply computing a range of composite indices, with the weights varying from 0 to 1 in increments of 0.1. The analyst would then subjectively decide which composite index to be most appropriate given the conditions of the contract.

[3] The general linear regression model can be applied to inherently linear models by a suitable transformation of the variables. For example, nonlinear cumulative cost growth patterns, sometimes closely approximated by logistics curves, may be transformed into a linear form before estimating by ordinary least squares.

Totaro (Defense Logistics Agency 1987) suggested that determining the weights for the composite index be a function of percent complete. Starting weights for the SPI and CPI were subjectively assigned by the analyst after consideration of program characteristics, such as the manpower loading projected by the contractor.

Haydon and Riether (ManTech Corporation for Navy Weapons Engineering Support Activity (NAVWESA), 1982) proposed a technique to develop a point estimate from a range of EACs computed using various formulas. First, a range of EACs is computed using index-based formulas evaluated by Covach, et al. (1981). Second, the range is expanded by 2.5 percent, and the median of this expanded range is taken as the point estimate for the EAC. Based on an analysis of 21 completed or nearly completed contracts (15 development, ,6 production) managed by the Navy, if the contractor's EAC was less than this point estimate, the point estimate was the more accurate forecast 79 percent of the time. A sample worksheet for the procedure and a numerical example are provided.

Regression-based methods. Three non-comparative studies proposed using regression analysis to model the curvilinear cumulative cost growth profile typical on defense contracts. As a group, the techniques proposed in the studies are well documented, complicated, and demand considerable knowledge of regression analysis. As such, they would not be easy to implement.

Sincavage (Army Aviation Systems Command, 1974) proposed using time series analysis to forecast the EAC. The computer-based model, "Time Series Analysis for Army Internal Systems Management" (TSARISM), uses moving average, autoregressive, or a combination of the two time series analysis techniques. As such, it is sensitive to the statistical problem of autocorrelation and requires many months of data before it can be developed. Accordingly, the model would only be useful during the later stages of a contract. Based on discussions with the author, the original documentation has been lost.

Olsen, et al. (Aeronautical Systems Division, 1976) described a time series forecasting technique used by the B-1 System Program Office. A computer program called "GETSA" developed by General Electric and leased by the B-1 SPO was used to forecast EACs. Other techniques, including regression analysis and exponential smoothing, are also briefly described. A numerical example is provided.

Busse (Air Command and Staff College, 1977) recommended an alternative way to develop coefficients for a non linear regression-based model developed by Karsch (1974). Although Busse made no comparisons with the Karsch model, a numerical example based on Karsch data was provided. Comparing the results of Busse with those of Karsch at several contract completion stages indicated that the Karsch model generated more accurate EACs.

Weida (Air Force Academy, 1977) proposed using nonlinear regression analysis to fit development program data to a normalized S-curve. After adjusting the data for inflation and statistical problems (heteroscedasticity and autocorrelation), Weida established that the S-curve was descriptive of cumulative cost growth on each of the 22 development programs which he examined. The normalized S-curve could then be used for both comparative and predictive purposes. A numerical example was provided. Although Weida's technique is complicated, it is compelling and deserves serious attention.

Chacko (Defense Systems Management College, 1981) proposed using a time series forecasting technique termed "adaptive forecasting." According to Chacko, five months of data are necessary before accurate estimates are possible. Essentially, the adaptive forecasting model adapts (changes) as each month's data become available. Accordingly, the model is best suited to short-term forecasting.

Watkins (Navy Postgraduate School, 1982) proposed using linear regression analysis and an adaptive form of the Rayleigh-Norden model. According to Watkins, the Rayleigh-Norden model is descriptive of life-cycle patterns of manpower buildup and phaseout on defense contracts. In this study, the model is used in a linear regression analysis of ACWP against time. Quarterly data from three contracts submitting C/SSRs were used in the regression analysis. The data were adjusted for inflation. There was no adjustment for autocorrelation.

Other methods. These non-comparative studies propose forecasting methods which are based on techniques other than regression analysis or performance indices.

El-Sabban (Army Aviation Systems Command, 1973) proposed the use of Bayesian probability theory to calculate an EAC. The method assumes a normal probability distribution, a mean, and a variance for the EAC at the start of the contract. As current data on ACWP become available, the “prior probability distribution” of the EAC is revised using Bayes’s formula. Because the model is not dependent upon a long history of performance data, it could be especially useful in the early stages of a contract. Overall, the method is clearly presented, although its accuracy was later challenged by Hayes (1977). An example is provided.

Holeman (Defense Systems Management College, 1974) proposed a “performance factor” determined by subjective judgment as a “product improved method” of developing the EAC. Used like a performance index, the performance factor would include a linear combination of variables (contract changes, inflation, schedule variances, overhead fluctuations, technical risk, and cost history). Determining the relative contribution of each is left to the analyst’s judgment. Holeman also suggested that a range of EACs should be subjectively determined and evaluated using simulation. A numerical example is provided.

COMPARATIVE STUDIES

Comparative studies compare the predictive accuracy of two or more EAC formulas. The general approach was to collect data on completed or nearly completed contracts, compute EACs using various formulas, and compare each to the reported Cost At Completion (CAC). For studies using a single contract, the comparison was based on deviation from the CAC in dollars; for studies using multiple contracts, the comparison was based on percent deviation from the CAC. Other comparison criteria included the coefficient of determination (R-squared) and ranking techniques.

Some studies were more thorough than others, and adjusted the data for various problems, such as scope damages, baseline changes, and inflation. In addition, the better studies checked the sensitivity of the result to the stage of completion, the type of weapon system, and the type of contract (production or development).

Twelve comparative studies are summarized in Table II by author, year, Service (Army, Navy, Air Force), contract phase (development, production), and formula/model category (index-based, regression-based). Four subcategories of index-based formulas are presented (CPI, SPI, SCI, Composite), and ten composite indices. Within each of these, the type of index is listed. The table shows six CPIs (CPIm, CPI3, CPI6, CPI12, CPIc, other), two SPIs (SPIc, other), and ten composite indices. For the composite indices, the weighting for SPIc is shown to ay from 10 to 90 percent in increments of 10 percent. The “other” category is for any other possibility for a composite index (eg. a weighting of .75 on a SPI6). Two subcategories of regression models are listed (linear, nonlinear).

The numbers in the columns for development and production contracts indicate the number of contracts of that kind that were used in the study. The numbers in the formula columns indicate the number of formulas of that type that were evaluated. For example, Riedel (1989) evaluated six formulas using data from 16 development and 40 production contracts that were managed by the Air Force. The six formulas were CPIm, CPI3, CPIc, SCIc, and two composite indices (.2SPIc+.8CPIc, another weighting).

A brief description of each comparative study follows. The order is chronological, consistent with Table II.

Karsch (Aeronautical Systems Division, 1974) compared one index based formula (CPIc) and two nonlinear models using data from a development contract managed by the Air Force. In the nonlinear models, termed “constrained” and “unconstrained,” Karsch regressed ACWPc against BCWPc through 60 months. In the constrained model, the coefficients was held constant; in the unconstrained model, the coefficient was allowed to vary. The constrained model produced the most accurate EAC throughout most of the contract's life. Karsch recommended that production programs be analyzed to establish generalizability and a range of values for the fixed coefficient in the constrained model.

Karsch (1976) subsequently evaluated the same formula and models using 13 production contracts (aircraft and missile) managed by the Air Force. The constrained model was again the most accurate, for both aircraft and missile contracts, and for nearly all the life of every contract examined. Karsch recommended additional research to establish generalizability. For both studies, sample data were provided.

Heydinger (Space and Missile Systems Organization (SAMSO), 1977) evaluated seven formulas and models with 42 months of CPR data from one development contract managed by the Air Force. There were four index-based formulas (CPIm, CPIc, two versions of CPI3) and three regression-based models. The two versions of CPI3 were defined as in Equations 6 and 8 of this paper. The regression-based models included the Karsch constrained model and two models proposed by SAMSO. Each of the SAMSO models regressed ACWP and BCWP against time. One assumed linearity; the other assumed an Erlang equation was descriptive of the relationship.

Overall, the SAMSO model using the Erlang equation was the most accurate throughout the contract's life. The Karsch model was more accurate than the CPI3 equations in the early and late stages of the contract. Of the index-based formulas, the CPI3 equations were most accurate. The CPI3 formula that averaged three monthly CPIs (Equation 8) was slightly more accurate than the other CPI3 formula (Equation 6). Because of the limited sample, the author advised against generalizing to other contracts and recommended further research.

Hayes (Air Force Institute of Technology. 1977) evaluated one index-based formula (CPIc), a nonlinear regression model (Karsch 1974), and a modified version of El-Sabban's model (1973) using data from five contracts (three development, two production) managed by the Air Force. Results indicated the Karsch model as most accurate. The modified El-Sabban model was more accurate than the index-based formulas (CPIc).

Land and Preston (Air Force Institute of Technology, 1980) evaluated four index-based and two regression models using data from 20 aircraft contracts managed by the Air Force. The exact numbers of production and development were not reported. The index-based formulas include CPIm, CPIc, and CPI3. The nonlinear regression models evaluated were the "constrained" and "unconstrained" exponential models proposed by Karsch (1980). Overall, the results showed that the index-based formulas were more accurate the Karsch models, with CPIc the most accurate of the index-based formulas. CPI3, computed as in Equation 6, was slightly more accurate than CPI3, computed in Equation 8.

Covach, *et al.,* (Man Tech Corporation for Navy Weapons Engineering Support Activity, 1981) evaluated 24 formulas and models using data from 17 contracts (14 development, 3 production) managed by the Navy. The formulas included 12 index-based formulas and 12 regression-based models. The CPI-based formulas were CPIm, two CPI3s, two CPI6s, CPI12, CPIc, and three other kinds. Average CPIs were as defined in Equations 6 and 8. The other CPIs involved dividing an average CPI into BAC.[4] The two other index-based formulas were SPIc and an unusual use of SPI, where SPIc is divided into BAC. The 12 regression-based models used ACWPc, BCWPc, or CPIc as the dependent variable, and BCWPc or Time (months) as the independent variable. The SAMSO nonlinear model (Heydinger, 1977) was also considered for evaluation, but rejected because it was too unstable. Unfortunately, the index-based formulas were not compared to the regression-based models.

A summary of the results from comparing index-based formulas is provided in Table III. Average CPIs defined by Equation 6 were generally more accurate than those defined by Equation 8. The equations, which involved dividing an averaged index into BAC, were completely discredited. Results of comparing the regression model were less clear. No one model always performed well. Once a model began to perform well, it usually continued to be the best regression-based model. Finally, for all of the formulas and

[4] Dividing anything other than CPIc into the BAC is an incorrect algebraic simplification of the basic EAC formula presented as Equation 1 in this paper.

models evaluated, EACs computed from level one data in the work breakdown structure were as accurate as EACs computed at lower levels and summed to level one.

Bright and Howard (Army Missile Command, 1981) evaluated 11 formulas and models using data from 11 development contracts managed by the Army. Nine index-based formulas (CPI3, CPI6, CPI12, CPIc, SPIc SCIc, SPIcxCPI6, .5 CPIc+.5SPIc, .75CPIc+.25SPIc) and two regression-based models (one linear, one nonlinear), with ACWP regressed against CPI, were evaluated at various contract stages.

Summarized results are shown in Table IV. In the early stage, Bright concluded that the two regression-based models performed better than the formulas; of the formulas, the composite indices were most accurate. The information content of the SPI was shown to decrease, as composite formulas giving larger weights to SPI were more accurate in the early stages of the contracts examined. In the middle stages, the average CPIs were most accurate. Bright suggests that when contracts have significant cost variance growth in the middle stages, an index averaged over a shorter period is more accurate than one averaged over a longer period. In the later stages, CPIc and SCI were more accurate. The SCI was also found to be a reasonably accurate index in the early stages of the contracts examined. Of various combinations of SCIs examined, SPIcxCPI6 was the most accurate.

Blythe (Aeronautical Systems Division, 1982) evaluated 12 composite indices using data from 26 (7 development, 19 production) contracts managed by the Air Force. Weights for the composite indices varied from 0 to 1, in .1 increments. Blythe's study differed from the others in that it derived a regression-based model for each index-based formula. The model was used to adjust the EAC, usually upward. Based on this innovative approach, Blythe found that adjusting the contractor's reported EAC was more accurate than any index based EACs, weighting the SPIc at .2 was the most the most accurate at any stage of completion. Blythe made no distinctions between development and production contracts. Cryer and Balthazor (1986) subsequently replicated Blythe's study, using the same data and methodology. The results were insensitive to whether the contracts were development or production.

Price (Air Force Institute of Technology, 1985) evaluated five index-based formulas and one linear regression model using data from 57 development contracts managed by the Air Force. The index-based formulas were CPIm, CPIc, CPI3, and two unusual composite indices. In the first composite formula, the schedule variance percentage (SV%) is multiplied by .75 and added to the cost variance percentage (CV%): 1-CV%+.75SV%. the second composite formula was defined as a weighted combination of three CPIs: .12CPIm+.24CPI3+.64CPIc. Rationale for those formulas was not provided. Results showed CPIc and the first composite formula to be the most accurate followed by CPI3 and the regression-based model.

Rutledge and DiDinato (Armament Division, 1986) evaluated five index-based formulas and one linear regression model using data from57 development contracts managed by the Air Force. The index-based formulas were CPIm, CPIc, CPI3, and two unusual composite indices. In the first composite formula, the schedule variance percentage (SV%) is multiplied by .75 and added to the cost variance percentage (CV%): 1-CV%+.75SV%. the second composite formula was defined as a weighted combination of three CPIs: .12CPIm+.24CPI3+.64CPIc. Rationale for these formulas was not provided. Results showed CPIc and the first composite formula to be the most accurate followed by CPI3 and the regression model.

Riedel and Chance (Aeronautical Division, 1986) evaluated six index-based formulas using data from 56 contracts (16 development, 40 production) managed by the Air Force. The six formulas (CPIm, CPI3, CPIc, SCIc, .2SPIc+.8CPIc, and (S)CPIc+(1-X)SPIc, where X = percent complete) were evaluated at four completion stages (25%, 50%, 75%, 100%). The sensitivity of the results to the type of weapon system (8 aircraft, 5 avionics, and 5 engines) was also evaluated. Generally, EACs for production contracts were more accurate than EACs for development contracts. More specific results are summarized in Table V. The term "PC" stands for the formula using percent complete to adjust the weights in the composite index. The term "20/80" stands for a 20 percent weight on the SPTc and an 80 percent weight on the CPIc of the composite index.

CONCLUSION

Attempting to generalize from such a diverse set of EAC research is dangerous. However, the larger and more diverse the number of contracts used in the study, the more compelling the generalization. Of the 13 comparative studies reviewed, the number of contracts varied from one (Karsch, 1974) to 56 (Riedel, 1989) or 57 (Price, 1985), with Riedel's sample much more diverse than Price's sample. With this caveat in mind, the following generalizations are provided:

1. The accuracy of regression-based models over index-based formulas has not been established. Most of the early research in EAC forecasting (e.g., Karsch, Heydinger, Sincavage, Weida) involved nonlinear regression or time series analysis, showed promise, but suffered from small sample sizes. Studies using larger sample sizes (Land, Bright) had mixed results. Bright showed a regression model to be more accurate than select index-based formulas in the early stages, but suggested that using the model was not popular because management would not support early, pessimistic forecasts, however accurate! Despite Bright's comment, with the wide availability and decreased cost of computer technology and statistical software, additional research exploring the potential of regression analysis as a forecasting tool is badly needed. The innovative and well documented work by Weida and Blythe is compelling and worthy of serious attention. In short, we have the tools and should use them.

2. The accuracy of index-based formulas depends on the type of system, and the stage and phase of the contracts. As detailed in Tables III, IV, and V, the larger studies (Covach, Bright, Riedel) document that no one formula is always best.

    a. Assigning a greater weight to the SPI early in the contract is appropriate. Because the SPI is driven to unity, it looses its predictive value as the contract progresses. SCI-based formulas were thus shown to be better predictors in the early stages by Covach, Bright, and Riedel. In the late stages, the SCIc and CPIc have nearly the same values, and were shown to be accurate predictors by Bright and Riedel.

    b. The long-asserted (Wallender) accuracy of the composite index with a 20/80 percent weighting on SCI and CPI, respectively, is not supported by the evidence. The most recent and comprehensive study (Riedel) documents the accuracy on this composite index on only a small subset of the contracts. Accordingly, the arbitrary use of this weighting should be avoided. There is no substitute for familiarity with the contract.

    c. Averaging over short periods(e.g., 3 months) is more accurate than averaging over longer periods (e.g., 6-12 months), especially during the middle stages of a contract when costs are often accelerating (Bright, Covach, Riedel). In addition, computing the average as the "ratio of sums" (Equations 6,7) rather than as the "average of monthly indices" (Equations 8,9) results in slightly more accurate forecasts (Land, Covach).

It is hoped that this comprehensive review will be of value to analysts and managers involved with EAC forecasting. The use of *Performance Analyzer* or other analysis software has reduced the mathematical burden of developing independent EACs, but it is no substitute for judgment. In addition, until the "abiding cultural problems" referenced by Beach are resolved, the accuracy of EAC forecasting is of secondary importance.

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TABLE I
SUMMARY OF NON-COMPARATIVE EAC RESEARCH

Author (year)	*Organization*	*Forecasting Method*
El-Sabban (1973)	Air Force	Bayes' theorem
Sincavage (1974)	Army	Time series analysis
Holeman (1975)	DSMC	Performance factor (subjective)
Olsen (1976)	Air Force	Regression/time series analysis
Busse (1977)	Air Force	Nonlinear regression analysis
Weida (1977)	Air Force	Nonlinear regression analysis
Jakawski (c1977)	Navy	Composite index
Parker (1980)	DLA	Composite index (subjective)
Lollar (1980)	Air Force	Composite index
Chacko (1981)	DSMC	Time series analysis
Haydon (1982)	Navy	EAC range analysis
Watkins (1982)	Navy	Time series analysis
Totaro (1987)	DLA	Composite index (subjective)

TABLE II
SUMMARY OF COMPARATIVE EAC RESEARCH

		Contract		*CPI*						*SPI*		*SCI*		*Composite*										*Regres*	
Author (year)	*Service*	*Dev*	*Prod*	*CPIm*	*CPI3*	*CPI6*	*CPI12*	*CPIc*	*Other*	*SPIc*	*Other*	*SCId*	*Other*	*10*	*20*	*30*	*40*	*50*	*60*	*70*	*80*	*90*	*Other*	*L*	*NL*
Karsch (1974)	USAF	1						1																	2
Karsch (1976)	USAF		13					1																	2
Heydinger (1977)	USAF	1		1	2			1																1	2
Hayes (1977)	USAF	3	2					1															1		1
Land (1980)	USAF	~10	~10	1	2			1																	2
Covach (1980)	USN	14	3	1	2	2	1	1	3		1	1												3	9
Bright (1981)	USA	11			1	1	1	1		1		1	1					1					1	1	1
Blythe (1982)	USAF	7	19					1		1				1	1	1	1	1	1	1	1	1	1		
Price (1985)	USAF	57		1	1			1															2	1	
Cryer (1986)	USAF	7	19					1		1				1	1	1	1	1	1	1	1	1	1		
Rutledge (1986)	USAF	13	2									1			1										
Riedel (1989)	USAF	16	40	1	1			1				1			1								1		

TABLE III
RESULTS OF EAC COMPARISONS (Covach, et al., 1981)
14 Development and 13 production Contracts (Navy)

Completion Stage	*Best Performing Formulas*
Early (0-40%)	CPI3, CPIc, SCIc
Middle (20-80%)	CPI3, CPI6, CPIc, SCIc
Late (60-100%)	CPI3, CPI6, CPI12

TABLE IV
RESULTS OF EAC COMPARISON (Bright and Howard, 1981)
11 Development Contracts (Army)

Completion Stage	*Best Performing Formula/Model*
Early (0-40%)	Regression, Composite, SPIc, SCI
Middle (20-80%)	CPI3, CPI6, CPI12
Late (60-100%)	CPIc, SCI

TABLE V
RESULTS OF EAC COMPARISON (Reidel and Chance, 1989)
16 Development and 40 Production Contracts (Air Force)

Phase	*System*	*---Completion stage---*				*Overall*
		25%	*50%*	*75%*	*100%*	
Development	Aircraft	SCIc	CPI3	CPI3	20/80	SCIc
Production	Aircraft	SCIc	CPI3	SCIc	CPIc	SCIc
Development	Avionics	SCIc	CPI3	SCIc	CPIc	CPI3
Production	Avionics	20/80	SCIc	20/80	SCIc	20/80
Development	Engine	CPIm	SCIc	CPI3	CPI3	CPI3
Production	Engine	PC	CPIc	SCIc	PC	CPIc